An improved redshift indicator for Gamma-Ray Bursts, based on the prompt emission

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Abstract. We propose an improved version of the redshift indicator developed by Atteia [1], which gets rid of the dependence on the burst duration and provides better estimates for high-redshift GRBs. We present first this redshift indicator, then its calibration with HETE-GRBs with known redshifts. We also provide an estimation of the redshift for 59 bursts, and we finally discuss the redshift distribution of HETE-bursts and the possible other applications of this redshift indicator.

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DESCRIPTION

In 2003, Atteia proposed $X_0 = N_\gamma/(E_{peak} \times \sqrt{T_{90}})$ as a possible redshift estimator [1], based on the $E_{peak} - E_{iso}$ correlation [2, 3] linking E_{peak}, the intrinsic peak energy of the νf_ν spectrum, and E_{iso}, the isotropic energy radiated by the source in its rest frame. In addition, Yonetoku et al. have shown that the $E_{peak} - L_{iso}$ correlation was less dispersed than the $E_{peak} - E_{iso}$ correlation (2004) [4].
The definition of our new redshift indicator is partly based on these two relations and is written as : $X = n_{15}/e_p$, where e_p is the observed peak energy and n_{15} the observed bolometric luminosity in units of photons and in the 15 sec. long interval containing the highest fluence. Thus, all the burst spectra are now done on the same duration in the observer frame.
To compute this estimator, the burst spectra are fit with a Band model [5] which gives us the spectral parameters : α, β, E_0 and the fluence in the energy range $[E_1 - E_2]$ of the detector. Then, as described in the paper of Atteia [1], the theoretical evolution of X with the redshift is computed for a "standard" GRB ($\alpha = -1$, $\beta = -2.3$, $E_0 = 250\ keV$), considering a "standard" cosmology ($\Omega_m = 0.3$, $H_0 = 65\ km.s^{-1}.Mpc^{-1}$, flat universe), and finally the estimation of the redshift is deduced by comparison between the value of X obtained for the GRB based on its spectral parameters, and the theoretical evolution of X. In the following we call this estimation *new pseudo-redshift* (hereafter *npz*).
In addition, errors on pseudo-redshifts are computed : considering first the errors on the spectral parameters obtained with the fit, 1000 values of X are simulated, then 1000 *npz* associated are also calculated, and errors on *npz* are so derived (the errors presented hereafter are at 90% confidence level).

CALIBRATION

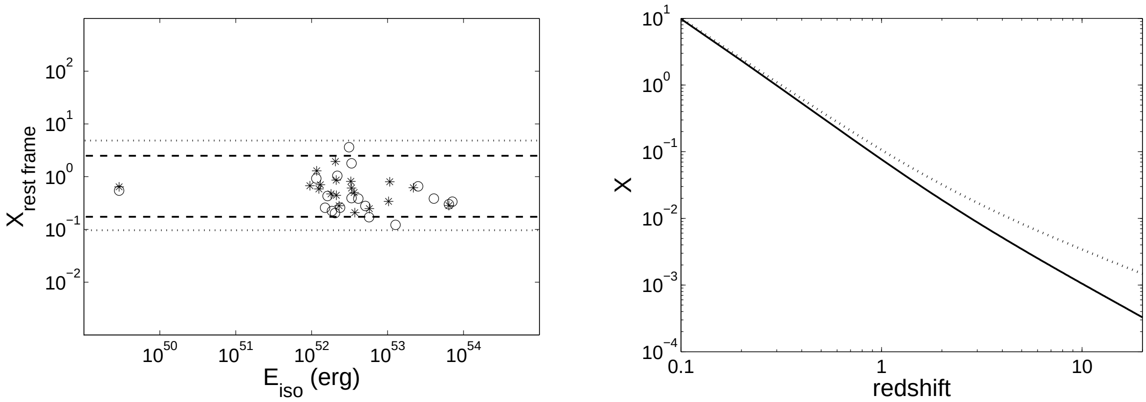

FIGURE 1. Left panel : intrinsic dispersion of the two redshift indicators : $X_0 = n_\gamma/(e_p \times \sqrt{t_{90}})$ *(circles)* and $X = n_{15}/e_p$ *(stars)* for 19 GRBs with spectroscopic redshift. Right panel : theoretical evolution of the two estimators *(dotted line for the previous indicator,solid line for the new one)* between $z = 0$ and $z = 20$.

A good redshift indicator must essentially satisfy two criteria : its independence on the bursts intrinsic characteristics, and its high dependence on the redshift.
Figure 1 *(left panel)* shows that whereas E_{iso} is extended on about 5 decades, the intrinsic dispersion of the new quantity X *(stars)* is only 1 decade against nearly 1.5 decade for the previous redshift indicator *(circles)*. In addition, the plot on the right panel shows the higher dependence of the new redshift indicator *(solid curve)* with the redshift, where the difference between the two estimators becomes significant for $z > 1$.
The redshift indicator is currently calibrated with 17 GRBs detected by *HETE-2* which have a spectroscopic redshift, and 2 additional GRBs (*050525* and *050603*) detected by *Konus-Wind* [6], [7]. The table on the figure 2 presents the results of the *npz* obtained with errors. We can notice *(right panel)* that the redshift estimate is always better than a factor 2 (*dashed lines*), except for *GRB051022* which has a factor 2.15 and a small

GRB	**npz**	**z**	**GRB**	**npz**	**z**
010921	0.58 ± 0.35	0.45	030528	0.64 ± 0.1	0.78
020124	1.77 ± 1.35	3.2	040924	0.82 ± 0.7	0.86
020813	1.19 ± 0.1	1.25	041006	0.68 ± 0.7	0.72
020903	0.32 ± 0.3	0.25	050408	0.70 ± 0.6	1.23
021004	2.53 ± 1.45	2.33	050525	0.70 ± 0.1	0.61
021211	1.17 ± 0.9	1.01	050603	2.73 ± 0.3	2.81
030115	1.57 ± 1.2	2.2	050922C	2.63 ± 1.6	2.19
030226	2.9 ± 1.55	1.99	051022	1.72 ± 0.2	0.8
030323	3.15 ± 1.65	3.37	970508	1.11 ± 1	0.835
030328	1.75 ± 1.3	1.52	980326	1.19 ± 1.1	1
030329	0.22 ± 0.05	0.17	990712	0.46 ± 0.55	0.43
030429	2.34 ± 1.4	2.65	991216	0.65 ± 0.55	1.02

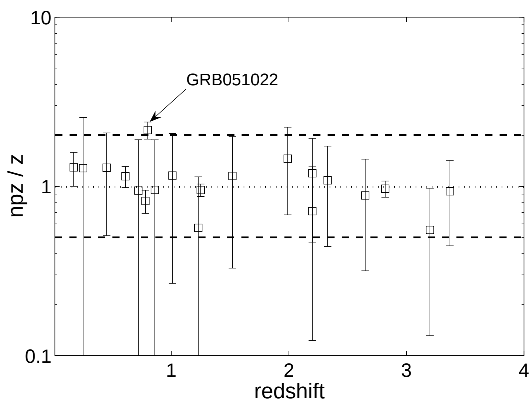

FIGURE 2. Left panel: redshift estimates for 24 bursts with known spectroscopic redshifts. Right panel: ratio npz/z for 20 bursts with known redshifts.

error *(see the arrow)*. We have yet to understand why this burst seems to be an outlier. Without this last GRB, the standard deviation is : $\sigma = 0.11$ *dex*. We have also computed the pseudo-redshift for 4 other bursts referenced in the literature [3, 8] : *GRB970508*, *980326*, *990712* and *991216*, which have a duration similar to the one used ($\sim 15 sec.$) in the derivation of the npz.

STUDY WITH THE NPZ

A sample of bursts without spectroscopic redshift

Taking into account all the long GRBs detected by the *FREGATE* instrument (6-400 keV) on-board of the satellite *HETE-2* which don't have spectroscopic redshift, we have computed a redshift-estimate for a sample of 34 bursts which had enough statistics to be correctly fit with *FREGATE* data. The results are given in the table presented in figure 3. The GRB redshift distribution is probably biased because of the small fraction of bursts which have a measure of their redshift. We tried to determine if this fact is confirmed for the *HETE-2* bursts, and what could be this distribution if we had a higher fraction of GRBs with known redshifts. Thus, we considered the redshift distribution of 3 groups of bursts.

The first group is composed of 19 *HETE*-bursts with redshift. This group has a cut in its redshift distribution at z = 3.3 *(figure 3, dotted line)*. Nevertheless, this cut seems to disappear and for the second group composed of 53 *HETE*-GRBs with redshift or pseudo-redshift *(solid line in figure 3)*, the cumulative distribution of this group is fully compatible with the group of 22 *SWIFT*-GRBs with measured redshift *(figure 3, dashed line)*. This result tends to show that the redshift-distribution of *HETE*-GRBs is biased at high-redshift.

Finally, we note that the sample studied contains few high-redshift GRBs : 4 GRBs only have a redshift higher than z = 4 (*GRB010612*, *030913*, *031026* and *051008*).

GRB	npz	GRB	npz
010612	5.25 ± 2.2	031109A	0.94 ± 0.2
010629	0.91 ± 0.9	031111A	2.14 ± 0.55
010928	3.64 ± 1.4	031203	2.17 ± 1.45
020127	2.21 ± 1.5	031220	1.53 ± 1.15
020305	1.98 ± 1.45	040319	1.79 ± 1.2
020331	2.21 ± 1.5	040423	1.26 ± 1
020418	1.4 ± 1	040425	2.23 ± 1.35
020801	1.21 ± 1	040511	1.83 ± 1.25
020812	3.48 ± 1.75	040709	1 ± 0.8
020819	1.21 ± 0.9	040912A	0.33 ± 0.35
021014	3.9 ± 1.9	040912B	2.94 ± 1.6
021016	2.8 ± 1.6	041016	3.49 ± 1.75
021104	1.22 ± 1.1	041211B	3.29 ± 1.6
030418	3.07 ± 1.7	050209	2.93 ± 1.6
030725	0.89 ± 0.3	051008	5.23 ± 2.2
030823	0.84 ± 0.7	051021	1.37 ± 1.2
030913	6.04 ± 2.7	051028	3.66 ± 1.8
031026	6.67 ± 2.9		

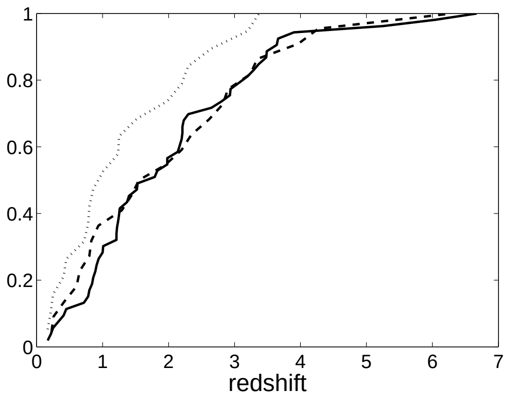

FIGURE 3. Left panel : redshift estimates for 35 bursts without redshift (sample of 34 *HETE*-bursts and *GRB051008* [9]). Right panel : cumulative distribution functions for *HETE*-bursts with redshift *(dotted line)*, *SWIFT*-bursts with redshift *(dashed line)* and a sample of 53 *HETE*-GRBs with redshift or pseudo-redshift *(solid line)*.

Comments on the *npz* and possible applications

Considering the most intense part of the GRBs seems a good way to improve the pseudo-redshift based on the prompt emission. Indeed, if we consider some examples such as *GRB010612* and *GRB031026*, they were previously found at $\widehat{z} = 9.5$ and 14 [10], compared to the *npz* which now gives respectively 5.3 and 6.7, values probably closer to the real redshift.

Moreover, it has solved the problem of *multi-peaks* GRBs in which the background was taken into account in the determination of t_{90}, which had for consequence a biased value of X_0. For example, *GRB020305* had an estimation of 5.88 [10], and is now found at 1.98 ± 1.45, in agreement with the spectroscopic constraints ($z \leq 2.8$, [11]).

Finally, if we consider recent determinations of spectroscopic redshift for old bursts, we can notice that *GRB030528* ($z = 0.782$, [12]) has a close npz of 0.64. For *GRB020819*, we find a value of $npz = 1.21$, not close to the real redshift ($z = 0.41$, [13]), but the error ($\pm$ 0.9) which is also large makes the estimation compatible with the true redshift.

The development of the pseudo-redshift finds several possible applications.

As the pseudo-redshift are rapidly computed, they can tell us very quickly whether the burst is at low or high-redshift, which permits to choose the appropriate way of observation.

Other applications of pseudo-redshift could be the verification of the validity of the $E_p - E_{iso}$ relation found by Amati [3] for a large sample of GRBs [14].

Finally, having a large sample of GRBs with redshift (or estimation) should let us study some of their cosmological aspects such as their luminosity function or the evolution of their rate with the redshift.

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